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AUTHOR Pascoe, M. W.
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ABSTRACT

Following a description of the essential chemical and physical structures of most archive documents, this paper examines the various pollutants that can damage these documents and gives their characteristics. The pollutants are categorized as environmental (e.g., smokes, mineral dusts); exterior gas and vapor (e.g., oxygen, water, sulphur dioxide); and internal active pollutants (e.g., organic acids, aldehydes); and pollution from activities (e.g., burning fuels, air treatment systems). The kinds of damage caused by these pollutants are then discussed for seven types of materials: (1) carbohydrates, cellulose, starch and gums; (2) cellulose esters, nitrate, and acetate; (3) protein materials; (4) synthetic polymers; (5) natural organic materials; (6) metals and their compounds; and (7) colored organic substances. Anti-pollution strategies for archives are presented in three categories representing different approaches to the problem: elimination of the sources of pollution, preventing the entry of pollutants, and deactivation of pollutants within an archive. Guidelines for forecasting pollution and pollution auditing are also provided. A brief summary concludes the report and a 44-item annotated bibliography is attached. (EW)

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Impact of environmental pollution on the preservation of archives and records: a RAMP study

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IMPACT OF ENVIRONMENTAL POLLUTION ON THE PRESERVATION OF ARCHIVES AND RECORDS : A RAMP STUDY

prepared
by M.W. Pascoe

General Information Programme and UNISIST

United Nations, Educational,
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PREFACE

In order to assist in meeting the needs of Member States, particularly developing countries, in the specialized areas of Archives Administration and Records Management, the Division of the General Information Programme has developed a long-term Records and Archives Management Programme - RAMP.

The basic elements of RAMP reflect and contribute to the overall themes of the General Information Programme. RAMP thus includes projects, studies and other activities intented to :

- develop standards, rules, methods and other normative tools for the processing and transfer of specialized information and the creation of compatible information systems ;

- enable developing countries to set up their own data bases and to have access to those now in existence throughout the world, so as to increase the exchange and flow of information through the application of modern technologies ;

- promote the development of specialized regional information networks ;

- contribute to the harmonious development of compatible international information services and systems ;

- set up national information systems and improve the various components of these systems ;

- formulate development policies and plans in this field ;

- train information specialists and users and develop the national and regional potential for education and training in the information sciences, library science and archives administration.

After having shown the nature of the various archive documents, the author studies the different kinds of pollutants, and gives their characteristics. He also gives an analysis of the damage caused by these pollutants on the documents. One part of the study presents what could be called "anti-pollution strategies" for archives, suggesting means of prevention and control of pollution.

Finally, a useful bibliography and notes complete the study.

Comments and suggestions regarding the study are welcomed and should be addressed to the Division of the General Information Programme, Unesco, 7, Place de Fontenoy, 75700 Paris. Other studies prepared under the RAMP programme may also be obtained at the same address.

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2.0 INTRODUCTION

Pollution includes any substance that may adversely affect our possessions or lives. It may be in the form of particulate solids, liquids, gases or vapours. The sensitivity of historic materials to the various pollutants is very variable. It depends not only on the chemical and physical structure of the materials but also on other environmental factors, particularly temperature and relative humidity. Consideration of these two factors, though of great importance in archive management, is not central to this report.

Pollutants are created artificially by various industrial processes, accidents, and from some in-house activities and materials. But many arise from natural processes, some of which are sudden and dramatic, such as lightning, volcanoes and forest fires, whilst others derive from slow continuous processes such as the decay of animal and vegetable matter.

The results of pollution may be the structural breakdown of polymeric materials, that includes fibres, paper, sizes, adhesives and plastics, or they may involve chemical transformations, for instance, the corrosion of metals or the fading of dyes. Deposits of dirt which only discolour the records might be tolerated and as they are obvious need little attention here. But discolouration may be associated with more serious hidden processes, in which for instance, moulds might lead to the formation of colours and acids within paper.

Damage is reduced by the elimination of the sources of pollution or by preventing it from entering the archive. Such obvious precautions may be ineffective if pollution arises within the archive, either from an activity such as fumigation or cleaning, or from the use of unsuitable materials close to objects.

Pollution may be removed in ventilation plants or by absorption into the furnishings or fabric of the archive. Its effects are worse when it is allowed to concentrate. Ventilation and air movement are important to reduce the risk of creating local areas of cold and therefore more humidity, but also to dilute and disperse pollutants. There is a delicate balance between the quality of the air admitted from the outside and that already inside, as both are polluted to a degree, but from different sources. Unless that balance is correctly judged efforts in pollution control might be wasted. It is useful to note though that the general need for ventilation in buildings is to remove odours from the human bodies. These may be not be harmful to the records themselves, but they are the basis of general engineering practice in ventilation.

Protection against most degradative influences has long been effected by the creation of files and books, where only the outer surfaces are exposed. However, it is obvious from the discolouration on the pages of old books that some deterioration is caused by outside agencies, thus causing yellow and brown colouration. Boxing up files should overcome this edge deterioration, but it creates stagnant air which, in rooms, is thought to be undesirable. These studies draw attention to the chemical pollution that might be made worse in closed boxes. In

considering the details of boxing there are many factors to assess, flood, theft, access, fire and mould are all difficult to quantify.

In pollution studies only a general estimate is possible about what exactly is present and in what quantity. But it is becoming more clear what effects certain pollutants have on some materials. This study draws attention to the variety of materials and their sensitivities.

The timescale of deterioration is difficult to predict unless strictly relevant examples already exist. General experience is important, but must be seen in a correct historical context. The massive increase in industrial urban pollution roughly coincided with chemical treatments of paper pulps and leather and also with the manufacture of many unstable dyestuffs. Both influences worked together to hasten deterioration. Furthermore, the much smaller quantities of historic paper, which are fundamentally more resistant, may have in any case been better protected on account of their age and rarity. Whilst accurate forecasts cannot be expected, it is possible to sense where the greatest effects will arise. Remedies and countermeasures are considered in strategic terms. Progress everywhere depends on the resources available but primarily on awareness, whose creation is a prime aim of this study.

If any aspects require further enquiry or investigation, an annotated bibliography is given, so that readers may enlarge and infill the details they require. Engineering particulars of plant and its specification are not emphasized. It is important that realism should be applied to any standards, it must be possible in the regular life of an archive to check that these standards are being achieved. Meanwhile the state and disposition of the records requires continuous and careful attention, especially those modern formats of photography and digitised information.

3.0 THE NATURE OF ARCHIVE MATERIALS

The essential chemical and physical structures of most of the materials in archives are broadly understood, but their actual behaviour may be affected by unknown complications associated with the large effects of additives or impurities on the behaviour. Such considerations are particularly important with modern papers and plastics. It is more difficult to predict the behaviour of graphic marks and images because of their great variety and chemical complexity, even greater than their substrates. Any reliance placed on accelerated testing implies several assumptions. In practice there is little opportunity even for extensive experiments. Judgements therefore have to be made from general scientific knowledge of the principles of degradation in conjunction with empirical observations made on archives materials over very long periods of time. An awareness of the degradation processes of polymers is necessary for predictions of the behaviour of most archival materials, which are mainly composed of polymers.

Polymers are simply very long chainlike molecules and form the basis of most record materials, including the fibres in papers, skins, the sizes and coatings and many ink and paint binders. In addition films, tapes, discs and even glass are essentially polymeric. Protein polymers form the fibres of wool, hairs and silks, and collagen which is the basis of leather, parchment and vellum, and the gelatines which are derived from them. The chains may be of great length, with some 10,000 units joined together, yet the whole chain is too small to be seen in an optical microscope. If the chain structure is simple and symmetrical then crystalline regions of tightly packed bundles can form. There will however always be some non-crystalline regions even in a well ordered polymer. The crystalline components confer strength, stiffness and a degree of resistance to chemicals because the permeability, and hence access, is restricted. Crystallinity is then a defence against chemical pollution. Some examples of crystalline polymers found in archives are :-

cellulose	paper, cotton, linen
proteins	wool, silk, hairs
poly(ethylene)	packaging film
poly(ethyleneterephthalate)	encapsulating film

In such substances the chains may through accident, aging or design, become connected onto another by forming new chemical bonds called cross-linking. This usually makes the material harder and brittle. If however some of the chain linkages become broken through chemical attack or from the action of other agencies such as light, heat or radiation, then the material usually becomes weaker and fragile. Both types of degradation make archival materials difficult to handle. They may both occur together.

Amorphous, that is non-crystalline, materials are rigid or rubbery according to their temperature, but they are inevitably permeable to chemicals, especially small molecules such as water, acids, ozone and oxygen. Chemical attack therefore is to be expected in amorphous regions of crystalline polymers as well as in polymers that are entirely amorphous. Quite small amounts of crosslinking or of chainbreaking cause a big change in handling properties, generally for the the worse. If only 1 or 2% of the linkages are so changed the effects are noticeable.

By contrast polymers which are highly crosslinked by design are apparently very resistant to chemical attack because they have such a great preponderance of crosslinkages that the loss of a few would be barely detectable. These substances are however rather rigid and somewhat brittle. Such thermoset or 'cured' polymers include :-

vulcanised rubber & gutta percha

old oil paint and varnishes

amino-formaldehyde resins (wood glues & paper strengtheners)

phenol-formaldehyde resins (plastic laminates on wood - plywood)

These useful materials cause problems because their curing reactions may not be completed and their ingredients or byproducts may act as pollutants as they evaporate into the surrounding air.

Glasses are highly crosslinked silica networks with great chemical stability, but they include a variety of metal ions which may diffuse out into condensation droplets and make them very alkaline.

Metals and their alloys can be considered to be the ultimate in crosslinking. Each atom is firmly bonded and attracted to all of its neighbours, thus producing a very tightly packed highly organised crystal structure. This accounts for their generally high densities but also for their impermeability to all gases, which makes even thin films of metal a perfect barrier to pollutants so long as the metal does not corrode away.

4.0 THE NATURE OF POLLUTANTS

4.1 Environmental pollutants

Environmental pollutants from outside are considered as smokes, dusts, gases and vapours. Those originating outside are reviewed first.

4.1.1 Smokes

Smokes result from the incomplete combustion of fuels such as coals, oil, woods, gas and rubbish. The black colour is essentially carbon, itself a very inert substance, but the particles are surrounded by oily and tarry substances. These can be quite acidic, even if from wood smokes. They cause the carbon particles to stick to surfaces.

4.1.2 Mineral dusts

Mineral dusts and smokes arise from volcanoes, quarrying, dust storms from high winds, and industrial processes including combustion including those involving cement and lime. The finest particles are carried over great distances. If they are of geological origin, it is probable that they would not cause chemical damage to records because such dusts are very inert, being fully oxidised. Cement and lime dusts are very alkaline and cause an unusual form of degradation. Acidic sulphate bearing ultra-fine dusts also travel great distances and are ascribed to coal combustion in electricity generating plants.

4.1.3 Salt dusts

Salt dusts may be deposited after the evaporation of sea spray. The main components are sodium chloride and magnesium chloride. Neither is an active chemical but they would assist in the corrosion of metals.

4.1.4 Petrol engine exhaust particulates

Particles of lead oxides are dispersed from petrol engines using leaded fuels. Though toxic it is useful to recognise that there is a long history of the use of lead compounds as grounds on record materials and in inks and pigments.

4.2 Exterior gas and vapour pollutants

Active gases and vapours which may be expected to harm record materials and which are found in polluted atmospheres are :-

oxygen (O_2), water (H_2O), sulphur dioxide (SO_2),

oxides of nitrogen (NO_x), ozone (O_3), hydrogen sulphide (H_2S),

ammonia (NH_3).

4.2.1 Oxygen (O_2)

Oxygen from the air permeates most organic materials and though not normally thought of as a pollutant, certainly contributes to the slow and continuous decay of almost all organic materials. Objects such as leather, wood, and corpses are preserved for long periods if buried under muds which allow oxygen free conditions.

4.2.2 Water (H_2O)

Water vapour is always present and plays various roles on the breakdown of materials. Direct reactions with organic materials may sever chemical bonds, called hydrolysis. Water swells the amorphous structures thereby making access of other pollutants easier. It is also an essential adjunct to all processes of biodeterioration. Many dyes fade more rapidly in humid conditions. Water accelerates the corrosion of metals.

4.2.3 Sulphur dioxide (SO_2)

Sulphur dioxide is a water soluble acidic gas originating in the combustion of coals, oils, and pyrites. It is slowly transformed into sulphuric acid which, as a strong and a very involatile liquid, remains within materials almost indefinitely. It causes much damage to archive materials generally, as well as many other substances such as stone and metals.

4.2.4 Oxides of nitrogen (NO_2 & NO)

Oxides of nitrogen are gases formed when air is heated to high temperatures as in lightning and in flames. They also arise from combustion in petrol engines and in furnaces and boilers using coal, wood, gas or oils. Cellulose nitrate, as in 'nitrate' film also emits these gases. They are soluble in water and form nitric (HNO_3) and nitrous acids (HNO_2). Nitric acid is a very strong acid and a powerful oxidising agent, it can thus cause the breakdown of many materials.

4.2.5 Oxone (O_3)

Ozone is an unstable form of oxygen, which is made in electric sparks and discharges and also from ultraviolet light. The nitrogen in air may also be involved in the electrical processes and convert to oxides of nitrogen. Ozone may not then be the only product. Ozone slowly decomposes, but it is in the meantime a powerful oxidising agent, and will affect many organic materials. It has many industrial uses including bleaching and sterilisation. It is highly toxic and has a characteristic odour which is sometimes noticed around photocopying machines.

4.2.6 Hydrogen sulphide (H_2S)

Hydrogen sulphide is a gas and also a weak acid, with a smell of rotting eggs, indicating that it is commonly produced by the

biodegradation of the proteins containing sulphur. Its weak acidity suggests it is not likely to affect organic materials seriously but it is very active in creating metal sulphides on some metals, particularly silver. It is also capable of turning some lead compound pigments into lead sulphide. These sulphides are black. Silver is the image material of most photographic processes and of some metal point drawings.

4.2.7 Ammonia (NH_3)

Ammonia is a water soluble gas giving alkaline solutions. It is formed from decaying organic matter and it noticable near poor sanitation. It rapidly forms salts with other gases which deposit on surfaces and may then contribute to localised acidity. It would not therefore be expected to travel very far before reacting.

4.2.8 Hydrocarbons

Hydrocarbons exist in great variety in the air, partly from incomplete combustion of fuels, and also from natural sources such as decaying organic matter, forests with resinous trees and underground reservoirs. They are not generally considered to have much effect on record materials.

4.3 Internal active pollutants

Pollutants from the inside of an archive are more varied and complex than most of the simple molecules in the atmosphere. The emission of gases and vapours has long been recognised as a cause of deterioration, hence it is important to maintain an awareness of these pollutants and their possible origins and effects. Improvements can begin almost immediately after a survey has revealed possible sources, often with little expense and without the delays and cost problems required by plant intended to reduce pollution. But the variety of materials which appear undesirable is very great. It is rarely possible to test each one, though the testing of materials for showcases and storage is becoming 'good practice' in museums. Some record materials themselves emit harmful vapours and gases. Some ingenuity is required to manage such collections. Often high levels of humidity and temperature exaggerate the production of the emanations. Harmful substances generated as a matter of course are considered first, and those created by activities within a building later.

organic acids (aliphatic carboxylic acids)

- methanoic (formic acid) $HCOOH$
- ethanoic (acetic acid) CH_3COOH
- propanoic $CH_3 \cdot (CH_2)_2 \cdot COOH$
- butanoic (butyric acid) $CH_3\text{-}(CH_2)_3\text{-}COOH$

aldehydes

- methanal (formaldehyde or formalin in water) HCHO

acids

- hydrogen chloride (hydrochloric acid in water) HCl
- hydrogen sulphide H_2S
- nitric acid HNO_3

peroxides

- hydrogen peroxide H_2O_2

All of these are known to damage archive and record materials. In addition there are many more substances which are complex in structure and therefore best described by their function rather than their composition.

- residual solvents (trapped temporarily in materials)
- residual monomers (unreacted ingredients of plastics)
- plasticisers (softening agents for plastics)
- antioxidants (in plastics and rubbers)
- fumigants, biocides and pesticides

It must be expected that this list will grow as knowledge increases. Before the effects on particular materials are considered their origins will be discussed.

4.3.1 Introduction

There is unfortunately no possibility of making an exhaustive list, but it should be possible from the examples discussed to sense when inappropriate and harmful materials might be encountered. Archivists do well to recognise a localised pollution problem. It may be confined to a sealed container, closed box or even a cupboard, a room or the whole building. In making an assessment a useful indicator is the odour of some of these emissions. A sensitive nose may give a useful warning, when for instance old films are decomposing, but it is not infallable, consistent or perhaps even sensitive enough. But any unusual smells should always be treated as a warning and further investigations are appropriate. The smell of chemical compounds is not related to their toxicity or to the harm they may do to record materials. Nevertheless a trained nose is a valuable guide to pollution detection in most archives.

4.3.1.1 Organic acids

Organic acids arise from the breakdown of natural materials, particularly woods of all kinds, especially, but not necessarily only when they are relatively new. They are also generated by the fermentation of sugar bearing organic substances which give products like vinegar. A smell of vinegar suggests that acetic acid is present, it is sometimes detected in cans of 'Safety' film. This film base is a cellulose acetate which has slowly reacted with water to give the volatile acetic acid. This reaction is termed 'hydrolysis' and is to be expected with all ester materials sooner or later. Cellulose acetate has found wide use as a lamination film for fragile papers, and for encapsulation. Poly(vinylacetate) and its copolymers are widely used in the form of emulsions in adhesives and paints. Its copolymer with vinyl chloride is the normal plastic used for long playing sound recording discs.

Acetic acid is also one of many substances evolved when drying oils, and products derived from them are exposed to air, the emission continues over long periods of time. Drying oils are unsaturated fatty acid esters of glycerol. Most drying oils originate in plants eg. linseed, soya and tung oil. They have been used widely since antiquity and in this century have been modified by grafting onto synthetic structures such as alkyds polyesters and polyurethanes, for use in paints and inks. Such products and their unpigmented varnishes are widely used and may be suspected if the products are soluble (or thinnable) in white spirit. As well as organic acids these emit other harmful species such as aldehydes and peroxides.

4.3.1.2 Aldehydes

Aldehydes are very reactive compounds which are strong reducing agents, but they have many other reactions. Formaldehyde readily oxides during its action as a reducing agent to formic acid which is known to attack metals. It also reacts with proteins and crosslinks the chains, causing some hardening. Photographic emulsions are deliberately hardened in this way, the same action takes place in its role as a preservative for tissues and as a biocide. Emissions of formaldehyde from modern furniture and cavity wall insulation are currently thought to affect the health of people working in buildings. It arises from the urea-formaldehyde polymers used to make the adhesives and foams.

4.3.1.3 Peroxides

Peroxides and particularly hydrogen peroxide are particularly harmful, notably to photographic materials. Hydrogen peroxide is rather unstable and a powerful oxidising agent. It is a water soluble gas and is a byproduct of the oxidation of various organic substances such as drying oils.

4.3.1.4 Hydrochloric acid

Hydrogen chloride gives the very strong but non-oxidising hydrochloric acid in water. It forms when some polymers containing chlorine break down. Serious acidic pollution may be widespread in a building after an electrical fire when PVC insulation is burnt. Many such polymers are not very stable and can only be used when special stabilisers are compounded with them. Poly(vinylchloride) (PVC) is the best known example. It has been used as a paper laminating film and is often found in sleeves for colour transparencies. Poly(vinylidenechloride) (PVDC) is also unstable and, because it confers water vapour barrier properties, it is used to improve the water resistance of other transparent films, such as regenerated cellulose. Chlorinated poly(isoprene), a modified natural rubber has been used widely as a printing ink binder and is known to hydrolyse and give hydrochloric acid.

4.3.1.5 Nitric acid

Nitric acid HNO_3 derives from the hydrolysis of cellulose nitrate in film bases, lacquers, plastic mouldings and stiffened bookcloths. See 4.2.4.

4.3.1.6 Hydrogen sulphide

Hydrogen sulphide (H_2S) is formed by the hydrolysis of sulphur containing proteins, as found in wool, hairs and eggs, and also from vulcanised rubbers or fabrics dyed with sulphur dyes. See 4.2.7

4.3.1.7 Miscellaneous additives

Residual solvents, monomers, plasticisers, antioxidants and biocides are examples of minor components of common materials found in archives. Solvents sometimes take many months to diffuse out of materials and evaporate. The more involatile solvents are plasticisers and are used to soften polymers. They may be present in large quantities, perhaps as much as 30%. Whilst they are chosen to have a degree of inertness, many are esters, usually of weak organic acids, but some are phosphates. Some polymers retain monomers for long periods. Monomers are the building units for the polymer, they will generally be effective solvents for the polymer but are unsaturated and therefore also chemically reactive. Antioxidants are one class of stabilising additives necessary to make plastics fabrication possible. Like biocides and pesticides they cannot be briefly summarised. But they may on occasions be an important source of harmful substances.

4.3.2 Pollution from activities

In order to assess the possible sources of pollution in an archive it is useful to examine every activity which takes place, and also the nature and destiny of every substance that enters

the buildings and premises. Such a survey should ensure that all possible sources of pollution are recognised.

4.3.2.1 Burning fuels

Heating fuels such as coal, oil, gas and wood are all sources of many pollutants, if they are not removed by treatment at the boilerhouse they will have to be dispersed high and far away. If any other types of heater are used in offices, they may contribute to local pollution.

4.3.2.2 Air treatment systems

Air conditioning, ducted ventilation and humidifiers all require cleaning and maintenance which may involve the use of a number of potent chemicals and the creation of dusts. Particular attention has to be paid to the biological cleanliness of waters in these systems because of the risk of bacterial and fungal growth. Chemicals added to these waters to maintain the biological purity should be checked in the light of conservation knowledge. Water used in humidification systems should be free of salts and minerals. Deposits from boiler water treatment chemicals have been found on objects throughout a museum because that water was used for air humidification treatment. Chemicals used in cleaning out plants might be strong oxidising agents and it is important to check that these are never vented into the storage areas.

Any extraction system that uses electrostatic precipitators to remove the fine dust particles is likely to create ozone and oxides of nitrogen. Such equipment is better not used.

4.3.2.3 Cleaning, maintenance & decorating materials

The materials and processes used in cleaning, maintenance and repair may contribute to internal pollution, but it is not possible to predict the effects of individual agents. However it is expected that the use of hypochlorite bleaches, and ammonia based cleaning agents would need to be reviewed. The use of any drying oil products for floors or redecorating walls and woodwork would also seem to be harmful. In all these activities the odours give a useful warning that there might be an unnecessary generation of harmful gases.

4.3.2.4 Fumigants and biocides

Fumigation may leave residues of fumigants which become part of the collection until they eventually diffuse away or decompose. Similar fumigants are known to react with objects, methyl bromide for instance is known to corrode metals and crosslink proteins, so causing leather to become harder. Hydrogen cyanide affects some metals. Many library biocides contain compounds containing chlorine and sulphur. Questions about the possible breakdown of these compounds into known polluting agents need to be answered. The retention of biocides within records may be very desirable from the point of view of restraining

biodegradation, but the chemical consequences do require some study in case alternative procedures or treatments prove to be necessary.

4.3.2.5 Conservation and preservation activities

As well as surveying the fumigation materials, chambers and practices, all types of conservation and preservation treatments should be checked. It is unlikely that simple repair processes will cause any concern but all the chemical activities in a conservation or restoration area should be reviewed, especially if new processes are in use, or production-line treatments are planned. An example is the retanning process for bookbindings using solutions of aluminium formate, which could possibly create formic acid in the course of time. A treatment should not of course replace one problem for another unless all the factors have been judged beforehand.

4.3.2.6 Copying and photographic activities

Apart from conservation processes it is worth checking all the copying work which may be in occasional operation. Electrostatic copiers often smell of the ozone generated within, this must not reach the storage areas. Much photographic work involves chemicals and sulphurous substances from fixtures and toners. Diazo processes involve quantities of ammonia. Copying activities need careful scrutiny and ventilation should be carefully designed to avoid contamination of collections.

5.0 THE NATURE AND DEGRADATION FROM POLLUTION OF MATERIALS IN ARCHIVES

Even though the variety of substances in an archive is very great, their stucture, composition and behaviour can be broadly understood. But the degradation processes themselves are highly complex, consequently judgements and opinions about pollution resistance have to be based on our general knowledge of polymer degradation. Most studies of polymer degradation are made following artificially severe conditions of ageing. Very long exposures at ambient temperatures are rare and then often complicated by the effects of light, which should be discounted in an archive. Whilst there is endless scope for future studies, a view is needed immediately about the probable effects. Several types of archival material are considered in the light of their chemical composition.

5.1 Carbohydrates

Carbohydrates form the bulk of material in all archives. As combinations of hydrogen, carbon and oxygen, they are potentially unlimited in number, but fortunately only a very few types of chemical structural elements are important in natural materials. Examples are:

cellulose	-	fibres in paper cotton & linen
hemicelluloses	-	binders in plants and trees
starches	-	sizes and pastes
gums & mucillages	-	adhesives and binders

All of these materials have important structural similarities. They consist of a series of rings joined together by oxygen atoms (ether linkage). Each ring is made up of five carbon and one oxygen atoms. Another carbon atom forms a short branch on the ring. Each unit has three hydroxyl (-OH) groups, which have a strong affinity for water. The ring unit, conveniently called a glucose residue, as it is similar in structure to the sugar glucose, gives a useful model for discussion.

In cellulose the chains made up from these ring structures are originally very long in plants and trees, up to 10,000 units may be joined up to form the polymer chains. It happens that the precise configuration of the glucose rings in the chain allows the molecules to pack neatly together and form crystallites, so confering the necessary stiffness and stability to the molecules and fibres in the plant world. The crystallites also restrict the access of water and thereby minimise its effect on the fibres, and consequently on papers. Crystallinity in polymers can never be complete; too much might make make the fibres too brittle, too little would make them more sensitive to water.

Papers retain sufficient strength to be usable even when the cellulose molecules are greatly shortened as they become

degraded. Only when the chains are reduced to about 500 units of rings from the original 10,000 or so, does the handling properties of paper become very poor. Hence much degradation may pass unnoticed. The ring linkages are broken by hydrolysis (splitting with water) and this reaction proceeds much faster in acid conditions. Certainly the sulphuric and nitric acids created in papers through absorption of pollution are the prime factors in the breakdown of cellulose fibres. They are attacked primarily in the non-crystalline regions because both water and the acids can penetrate them readily. Crystalline zones are much less affected. Only a few hydrolytic bond breakages are required to reduce the original molecule to the danger level, when paper becomes too weak to handle.

By contrast, starch molecules are, because of a slight but crucial structural variation, much more open in form. Large spirals predominate and these are complicated further by the presence of some branching on the spirals. Starches then are extremely accessible to water and other substances. They swell greatly in water and do not have the strength or stiffness of cellulose. Starches are readily broken down: commercial glucose is made from starches by hydrolysis using hot dilute hydrochloric acid. The branching of starch however does reduce the risk of catastrophic breakdown with a small amount of degradation. Cutting the linkage is not so effective as in cellulose which is a single continuous chain, and so easily fragmented.

Oxidising agents such as air, hydrogen peroxide, ozone and nitric acid also attack these chains of glucose rings, but generally by altering the side groups on the rings. Hydroxyls may than become altered to give groups that confer colour, and some acid groups may also form on the side. As the integrity of the main chain is broadly unaffected the materials maintain their general strength. Thus hydrolysis and oxidation lead to different types of degradation. Obviously the loss of strength is the more serious, which is why acidity is always considered to be the most important factor. Discolouration by oxidation will happen in any case because we cannot sensibly exclude oxygen from collections. The creation of organic groups (carboxyl groups - COOH) on the chains through oxidation does not seem to cause much harm as the acids are weak. Such acids have been applied to most papers quite by chance for they have been affected by perspiration which includes not only common salt (sodium chloride), but also lactic acid, a weak organic acid. Perspiration has not prevented many papers from lasting hundreds of years.

The degeneration of cellulose fibres is accelerated by catalysts, effective in very small quantities. Traces of iron and copper compounds with paper, possibly from corroded pins and staples will act as catalysts. This justifies their separation from the paper.

Gums and mucillages also consist of linked rings of carbohydrate rings, somewhat similar to the glucose molecules, but these gums have a much more branched structure than starches, and they contain some organic acid groups which form salts. Like starch they will sustain some hydrolytic breakdown without total collapse. But as non-crystalline substances they are extremely

permeable. Recently the role of peroxide diffusing through papers in books has been proposed to explain various stains and their distribution through successive pages. Peroxide generation takes place when organic objects break down. Evidently this seems to occur in papers. The strength loss is not great but peroxide formation can be serious with photographic images.

Other pollutants do not have a great effect on carbohydrates. Dusts however may only be a little unsightly, but in damp conditions they may attract water and help promote microbiodegradation.

5.2 Cellulose esters (nitrate and acetate)

As cellulose is not conveniently soluble in common liquids and has therefore been converted to become so, by exchanginng some of the side hydroxyl (OH) groups with nitrate or acetate groups, the substitution need not be complete, the extent of it affects the properties of these modified natural polymers. The conversions also cause some shortening of the long cellulose chains. The products are however usefully soluble in common organic solvents. Hence it becomes possible to manipulate these materials as plastics, and by casting or extrusion to form films and fibres of great importance.

The degradation of cellulose nitrate, particularly in the form of a film base, is well known, thought it is also to be expected in collodion photography and in the decay of pyroxylin (cellulose nitrate) impregnated book cloths, which have been widely used in bookbinding. The immediate concern is to recognise that as it decays through hydrolysis, nitric acid is produced in situ. This causes the acidity to increase and the process accelerates. More nitric acid is made and diffuses into the environment. Its powerful oxidising properties made it even more undesirable. Negatives of this material filed in an archive will then be a source of internal pollution. There are serious fire risks if such films are kept, the acids may also corrode metal cans. Extreme care and vigilance is necessary in identifying and separating these highly flammable items. The fire hazard makes it desirable to find other cellulose esters which are much less flammable, that is 'Safety film'.

Cellulose acetates were developed and have found similar uses as a film base, plastic mouldings materials and textile fibres. The ester groups show essentially the same hydrolysis reaction as the cellulose nitrate, but the acetic acid produced is neither a strong acid nor an oxidising agent. It is possible that the developing acidity assists in the breakdown of the cellulose chain, and its archival quality is being questioned. With a moderate degree of conversion the cellulose di-acetate is known to break down in cans of film, giving a strong smell of vinegar when the can is opened. The acetic acid is volatile.

Exposure to sulphur dioxide or oxides of nitrogen will cause degradation as they do with cellulose. Fundamentally there is little reason to think that the fully esterified cellulose tri-acetate would not hydrolyse. As such cine, microfilm, microfiche and magnetic tapes have been made with cellulose acetate bases there is an obvious concern for these formats.

However there are other causes of embrittlement as well as the breakdown of the polymer structure.

None of the cellulose derivatives are particularly flexible, nor are their long molecules easily folded and twisted, for they are built of large rings, each bearing bulky side groups which obstruct the molecular movements. Such materials need to be softened by plasticisers, usually required in considerable quantities, perhaps upto 30%. These substances may diffuse out of the plastic film and migrate into adjacent material or evaporate. They may cause no obvious harm, but as they were chosen to have some solvency and a low volatility they may cause images made with dyes to become a little blurred, eg on colour film. Most of the plasticisers are esters, generally of weak organic acids, however some used in film bases are phosphates. Should these hydrolyse in the course of time then phosphoric acid will be produced. It is not very volatile and as it is a stronger acid than the organics it would be expected to contribute to the further degradation of the polymers. Papers laminated with cellulose acetate may therefore be further degraded by the contact. Hot lamination would be expected to be even more active in promoting degradation. If the papers had been treated with alkaline buffer before lamination that might be enough to deal with the acids generated.

As all these cellulose esters are based on cellulose they will be expected to behave in a similar manner when exposed to oxidative pollution.

It is also probable that these materials might carry residual acids (e.g. sulphuric) used in the original production which would shorten their life and make them more active as internal sources of degradation.

5.3 Protein materials

Protein materials are highly complex, but there is a great deal of information about their structures, obtained mainly from studying the products of their hydrolysis. Proteins are built up mainly in chains from amino acids. About 25 different amino acids are found in natural products, but often only a few are regularly involved. Genetic material for instance uses only four. Some proteins form long and fairly simple chains which form crystallites as part of fibres. Hair, wool and silk are important examples. Keratin, the protein in wool, hair and horn is however crosslinked with small bridges of sulphur atoms. This extra reinforcement accounts for their durability and chemical resistance compared with silk which has no such sulphur bridges. It also explains the permanent curliness in hairs. The sulphur may be released in damp conditions forming hydrogen sulphide. (see 4.2.7). Other protein structures are non-crystalline and open in structure, they can absorb water to form gelatinous substances such as gelatines. These can be crosslinked and so hardened with formaldehyde (methanal), which might arise from pollution, or with tannins or alum. Crosslinking increases the resistance to chemical pollutants and also to microbiological attack. Nevertheless these structures are very porous to chemicals, for without this facility photographic chemistry would not take place in gelatine or albumen media, for which purpose the proteins have to have a resistance to a variety of processing reagents. Chemical durability is noted in hair, parchment and glue-bound paints, as these are all crosslinked. Silk however is vulnerable to chemical attack because it is a single chain structure, sensitive to only a few bond breakages by hydrolysis.

Egg protein exemplifies another gelatinous substance, used historically for binding tempera paints and for albumen photographic emulsions. It is rather more sensitive than gelatine in photographs. Collagen fibres form the basis of muscle and skins, but with a considerable degree of complex helical structure. In leathers and parchments they are protected from rotting by tanning or lime treatments. Such materials are prone to acid hydrolysis, much sulphuric acid (up to 5% w/w) is found in old bookbindings from pollution.

Proteins, unlike the carbohydrates, are also sensitive to alkaline attack. Cement or lime dust from a building or construction work may cause this. The hairs of thermohygrograph recorders are known to be affected by cement dust. Relative humidity figures might be very misleading in such circumstances.

5.4 Synthetic polymers and plastics

Synthetic polymers are increasingly found in archives in the form of packaging and storage materials or as part of the record materials themselves. The table indicates the uses of some of these materials.

poly(ethylene) (PE) ..... packaging film, lamination of documents coatings for photographic papers under the emulsion (resin coated papers)

poly(propylene) (PP) ..... packaging film, moulded boxes

poly(vinylchloride) plasticised (PVC) ..... packaging of colour transparencies and book dust covers and bindings

poly(vinylchloride-vinylacetate copolymer (PVC/PVAC) ..... long playing sound recording discs

poly(styrene) (PS) ..... sound recording discs and packaging

poly(methylmethacrylate) (PMMA). showcases and mounting work

acrylic copolymers ..... fixatives, binders, web repair, and adhesives

poly(amides) nylons ..... fibre web for heat lamination also modified into a soluble fixative

poly(ester) (PET) ..... film and tape base, fibre web for repairs, packaging by encapsulation

poly(carbonate) ..... tough transparent windows optical disc recordings

poly(vinylacetate-copolymers (PVAC) ..... latex adhesive for repairs and binder for decorative emulsion paints

poly(ester-urethane) ..... binder for oxides on magnetic tapes

urea formaldehyde (UF) ..... wood glue and wood composite binder foam cavity insulation, paper strengthener

melamine formaldehyde (MF) ..... plywood glue and furnishing laminate

phenol formaldehyde (PF) ..... plywood glue and furnishing laminate

There are considerable difficulties in assessing the stability of these materials, particularly when pollution is a factor, largely because of their novelty. Degradation studies are generally based on exposures to weather and sunlight, or from simulated tests using heat, high intensity lighting, humidity and perhaps

regular wetting and drying. Pollutants are not generally included. But degradation is known to be frequently dependent on minute traces of impurities, whose presence may not be expected. Traces of iron and copper compounds in paper accelerate decay greatly in some of these synthetic polymers, and this behaviour is not uncommon. On the other hand many synthetic polymers could not be used without the use of particular additives designed to retard degradation. Their presence in a sample cannot be assumed. Not every batch will be perfectly compounded. Ultimately enough detailed information may permit a more controlled use of synthetic materials. Critical users may need to be aware that the actual composition of a plastic may differ in important details from another batch or source. These variations could be expected to affect the degradation behaviour.

5.4.1 Poly(ethylene) (PE)

This polymer is effectively a very long wax molecule and therefore has a high degree of water and chemical resistance. Comparison with wax suggests it should have a long life but it is prone to oxidation, because of some structural anomalies. An antioxidant has been found to stain cellulose items packed in it. It is soft enough to embed fine particles of dirt.

5.4.2 Poly(propylene) (PP)

This has similar properties to poly(ethylene), though its strength, hardness, stiffness and transparency are greater. It is expected to be more affected by oxidation than poly(ethylene).

5.4.3 Poly(vinylchloride) plasticised (PVC)

This soft plastic has a relatively short life, as it becomes harder as it looses its plasticiser, and is at risk as a source of hydrochloric acid. It has then no justifiable place in an archive. Document folders and colour transparency holders may be made of such plastics.

5.4.4 Poly(vinylchloride/vinylacetate) (PVC/PVAC)

This type of material is designed for stability, the plasticiser is an integral part of the vinyl chains. Both components are in principle hydrolysable to give acids, but so far no signs of this are evident. As sound recording plastics they have several special additives for various particular purposes which is a common feature of most vinyl polymers.

5.4.5 Poly(styrene) (PS)

This hard non-crystalline polymer is not considered to be very durable, even if not plasticised. It oxidises and discolours fairly readily. Its resistance to water, acids and alkalis is very notable.

5.4.6 Poly(methylmethacrylate) (PMMA)

A rigid transparent polymer with resistance to acids and alkalis is much used in museums for mounts. It also has very good weather resistance. It may contain some residual monomer and maybe some peroxide but no reported harm has yet been ascribed to these.

5.4.7 Acrylic copolymers

A variety of copolymers related to the methacrylates are used in conservation, some with useful stability and some others crosslink. Emulsions are used in acrylic paints and paper repair, solutions are used in varnishes and lacquers. There are no known pollution problems with these materials.

5.4.8 Poly(amides) nylons

The simple chain poly(amides), nylons, are established fibres and films. They are generally free of additives, a rare quality in plastics. The amide linkages, like esters, are subject to hydrolysis, particularly in acid conditions. They are also affected seriously by oxidising acids (oxides of nitrogen) and so discolour. Webs of special polyamides are used in hot lamination of newsprint, in repair and conservation work.

Chemical modification of the simple structure gives a new material, which is soluble in alcohols, and used widely as a fixative and consolidant in paper conservation, but they become crosslinked in time under mildly acid conditions. These poly(amides) absorb water readily and pollutants would not find access difficult.

5.4.9 Poly(ester) (PET)

Poly(ethylene terephthalate) is the main example, it is a successful fibre and polymer film, with a small water absorption. Though subject in principle to hydrolysis its crystallinity and low water absorption give it stability. As such it normally contains no additives but films may be coated with other substances to improve the adhesion of inks and glues. These coatings might be a source of local pollution. Because of its strength, clarity and stability it is widely used to encapsulate documents and act as a base for magnetic and photographic records. So far no problems with pollution have been found in archival uses, though it is known to break down in ultraviolet light.

5.4.10 Poly(carbonate)

Their crystallinity and very low water absorption protect the ester linkages from hydrolysis, but they are subject to alkaline attack. Their impact resistance makes poly(carbonates) of special use in resisting physical attack, but a modern development is its use as a compact record disc for digitised information. In this application it is protected by a metal film

of aluminium or platinum. The aluminum will be vulnerable to corrosion unless coated effectively, but platinum does not react with corrosive pollutants.

5.4.11 Poly(vinylacetate copolymers)

These polymers, usually used in the form of emulsions, form the basis of most decorative wall paints, latex adhesives for paper and as consolidants. Their odour indicates that some organic volatile materials are present. Some may be unreacted monomer. The films remaining after the water in the emulsion has evaporated are soft enough to allow dirt penetration, but in the course of time they may crosslink and also hydrolyse to create acetic acid, which is volatile.

5.4.12 Poly(ester urethane)

These polymers are used as binders for magnetic oxides on plastic tapes for data storage on machine readable archives. The required physical and chemical stability is very great but evidently they can hydrolyse, but as the products are not very volatile, they are not lost and might rejoin together in the reversed reaction. The binders work quite well in the equilibrium state of partial hydrolysis. General pollution would not be expected to reach such tapes in the recommended storage conditions.

5.4.13 Urea formaldehyde (UF)

These highly crosslinked colourless hard and brittle resins have found many uses - as a wood glue, a binder for wood chip board, foams for thermal insulation of cavities in walls, part of some stoving paints for metal office furniture and as moulding plastic. They are also used to stiffen textile fibres and give greater wet strength to paper. A serious pollutant from all these sources is formaldehyde which affects proteins by crosslinking, and oxidises readily to formic acid which attacks several metals and also carbonates such as chalk. It also affects photographic collections, and human health, often office workers.

5.4.14 Melamine formaldehyde (MF)

These resins are very similar to the urea formaldehyde polymers, but being more expensive, are confined to applications where their notable stain resistance is required, such as laminated board. The formaldehyde emission problem is likely to be similar to that of urea-formaldehyde materials.

5.4.15 Phenol formaldehyde (PF)

These bakelite resins are always yellow, and have hidden uses in plywood glue and in binding plastic laminated boards. The formaldehyde problem is similar to the above.

5.5 Natural organic materials

Tree and plant products preceeded synthetic resins as useful polymers. Casting of items such as seals did not make great mechanical demands on them, but when compression moulded sound recordings were made, the necessary extra strength and toughness was achieved with more complex materials. Shellac and rubber technology made this progress possible in various applications.

5.5.1 Natural rubber poly(cis-isoprene)

This long chain hydrocarbon polymer is very reactive as it contains many double bonds in the long chains which can readily open up later for further varied chemical reactions. The basic polymer is sticky and tacky, useful for adhesive tapes, but if crosslinked by heating with sulphur or reacted with sulphur compounds, it can be partly vulcanised to give the common elastic band. As the crosslinking uses up only a fraction of the available double bonds, the cured rubbers remain chemically active, and so they are prone to further oxidation and decay, but especially in the presence of minute quantities of ozone, which causes rapid hardening and cracking. Extensive vulcanisation gives the very hard and resistant ebonite.

The reactive nature of rubber allows it to be converted to other useful substances such as isomerised (cyclised) or chlorinated rubbers, which find uses as binders in printing inks. Solutions of rubbers are used as adhesives, and another type of rubber adhesive is simply the original latex from the tree stabilised with ammonia. There are many ways in which rubbers can become included in an archive.

Inevitably the formulations are complex with many additives required to assist the curing and product behaviour. Excess sulphur and sulphides may be expected as well as a number of volatile compounds. Antioxidants in rubbers have been known to diffuse into new paints in the same room and prevent drying. Many undiscovered effects from rubber in the microenvironment are expected. But rubber compounds should be kept well clear of tarnishable metals, and sensitive pigments because of the sulphurous emmisions, and also away from any photographic materials based on silver images.

5.5.2 Gutta percha poly(trans isoprene)

Chemically this is identical with natural rubber, a small change in its configuration however gives different but useful moulding characteristics. Gutta percha has been used in book bindings and other craftwork. Its environmental polluting problems are similar to those of natural rubbers.

5.5.3 Shellac, rosin and natural resins

Shellac is principally a mixture of two hydroxy organic acids (aleuritic and shelloic), the latter is unsaturated and therefore reactive. There is also a portion of waxy material, insoluble in alcohols.

Rosin also has an unsaturated organic acid (abietic) as its main component.

These substances are affected by air and ozone. They are widely used for recordings, paper coatings and sizing. Shellac is the binder for many old disc recording which become more brittle as the shellac oxidises, but the effect is lessened by other additives such as waxes, resins and minerals fillers. In general acidic and alkaline pollutants would be expected to do little harm.

Other natural resins such as copals, dammar and asphaltum are all prone to oxidation and embrittlement. They are used in printing inks and perhaps in varnishes. Their chemistry is very complex and is appropriate to the degradation of many paintings in art galleries.

5.6 Metals and their compounds

5.6.1 Metals

Metallic corrosion is not only an outdoor pollution problem for, in museum collections tarnishing and corrosion are not uncommon even in closed containers. All metals but gold are oxidised, but the oxide films are often protective, thin and unseen, as with aluminium which as a metal is very active chemically, but its highly protective film makes most of its uses possible. Some oxide layers allow quite weak acids such as hydrogen sulphide, acetic or formic (ethanoic or methanoic) to attack the underlying metal, giving coloured sulphides or fluffy white salts. Corrosion is encouraged by damp conditions. These are used in the corrosion tests applied to materials proposed for museum cases and storage. A number of unsuitable materials have been eliminated through this procedure.

5.6.1.1 Aluminium

Unlike most metals, aluminium is attacked by acids and alkalis. Thickening of the oxide layers by anodising gives added protection. Corrosion activity is often concentrated and leads to the formation of pits. Acidic gases and cement dust would be the worst pollutants. The ultra thin layers of aluminium on polycarbonate in disc recordings might give most concern in an archive, but they would normally have a protective coating of transparent polymer.

5.6.1.2 Iron and steels

These rust and corrode when oxygen, acids, salts and sufficient humidity are available. Dry air and alkaline conditions prevent corrosion of iron and steel. The corrosion products cause paper to deteriorate more rapidly, and therefore pins and staples are best removed from documents.

5.6.1.3 Lead, copper and silver

Whilst resisting strong acids these metals are attacked by

oxidising acids. Hydrogen sulphide also induces tarnishing. Lead and its alloys are attacked by organic acids such as acetic and formic, which may come from woods, paints or varnishes and glues. Silver tarnishing is generally seen at the edges of daguerreotypes: it is important to recognise that the tarnish layers are extremely thin.

Metal point drawings are also vulnerable but they may already be tarnished or oxidised and still remain visible. Lead point graphic marks could disappear if organic acids have been active, by conversion to colourless lead compounds. Lead seals may also be affected.

5.6.1.4 Silver images in black and white photography

Traditional silver halide photography creates images made of extremely small particles of silver in a medium of porous gelatine or albumen. These silver particles may be very complex in shape and therefore have a disproportionately high surface area. The silver particles are thus wide open to chemical attack. A recognised mode is the oxidation of the metal to silver ions by oxidising pollutants. The silver ions so produced may then diffuse away from the image, and perhaps be reduced back to silver at another site later on. Such regenerated silver is seen as a yellow-brown colour, as the silver is even finer than originally; it is colloidal. Blemishes on microfilm are an important example of this process.

Most other pollutants are thought to affect photographs. Hydrogen sulphide would give a black silver sulphide that may escape notice, but it is quite possible that this sulphide might be converted further to a colourless sulphate, if acid pollution is present.

Photographic chemical reactions are very complex but it is recognised that great efforts must be made to exclude all pollutants from a collection. Close attention to the quality of ventilation and the storage materials is required to minimise pollution damage.

5.6.2 Metal oxides

The magnetic oxides of chromium and iron that are used in magnetic recording tapes and discs are very unreactive and are unlikely to be affected by chemical pollutants.

5.6.3 Inorganic compounds and compositions

5.6.3.1 Glasses

Glasses are noncrystalline networks of silicon and oxygen atoms with metal ions interspersed. In historic glasses some these ions migrate to the surface and in damp conditions form drops of strong alkali, typically sodium hydroxide. This can be very damaging to other materials; daguerreotypes have suffered in this way. White crystals of sodium formate have been found on the inside glass lid of sealed cardbox boxes because the exuded alkali had reacted with formic acid vapours in the box. Glasses

cannot be assumed to be inert or unreactive to acid pollution.

5.6.3.2 Inorganic white compounds

A few vulnerable compounds, which may be found in paper or as grounds on manuscripts, are considered.

5.6.3.2.1 Calcium carbonate $CaCO_3$

Like all carbonates it reacts with acids readily. Efflorescence has been reported on shells kept in wooden boxes from the acids emitted from woods, particularly oak. In papers the changes might not be noticed as all these salts are white.

5.6.3.2.2 White lead - basic lead carbonate $PbCO_3.Pb(OH)_2$

Sulphur dioxide pollution converts this to white lead sulphate, which like the lead salts formed by organic acid vapours might not be noticed. Any traces of hydrogen sulphide quickly blacken white lead through the formation of black lead sulphide.

5.6.3.3 Coloured inorganic substances

Papers may be coloured with such materials, either in bulk, on their surface or from paints and inks. Many pigments are affected by acids and alkalis, but the extent of the attack may be limited if they are protected by a liner or coating. Only a few sensitive pigments will be considered here.

5.6.3.3.1 Sulphur compounds

Ultramarine - lapis lazulae is a silicate mineral containing sulphur which is displaced as hydrogen sulphide by stronger acids, the colour is thereby lost. Such compounds have been included in papers to offset their yellowness. They, like the following are frequently found in paintings.

5.6.3.3.2 Carbonates and acetates

These copper compounds are used as blue or green pigments generally as basic salts. They are all sensitive to acid attack. The products of these reactions are water soluble and could diffuse away.

Azurite - carbonate

Malachite - carbonate

Verdigris - acetate

5.7 Coloured organic materials

Organic pigments are discrete solid particles, usually crystalline, whose outer layers will encounter pollutants first

and perhaps protect to a degree most of the colouring substance within. But with dyes and lake pigments, which are in effect dyed inorganic particles, there is no such protection and hence greater pollution effects would be expected with dyes and lakes. Dyes will be found as general colourants for papers, leathers and boards in archives, but almost all coloured images and graphic marks are likely to be composed of dyes, as are all coloured photographic images.

Coloured photographic prints are sometimes protected with lacquers. Those lacquer solvents are prone to form peroxides which can cause the magenta layer to yellow. This illustrates the power of such oxidising agents even in a photographic image free of metallic silver. As well as peroxides, and oxides of nitrogen, ozone is also active. Studies of water colour pigments in ozone atmospheres not much more concentrated than those found in some cities, show considerable fading of some pigments, especially those based on dyes. These molecules are coloured because they contain a string of alternating double and single bonds. These unsaturated double bonds are attacked and opened by oxidising agents and the colour is then lost or changed. Hence most organic colours could be at risk, but some very seriously. Some coloured compounds also change their structure according to the acidity of the environment. This is a useful property in measuring acidity in the laboratory, but not when images are changed. Other pollutant-induced changes may not be reversible.

All these coloured organic materials should be treated as materials which are very sensitive to pollution. They cannot be indentified easily and therefore precautions to protect the most sensitive against pollutants, light and high relative humidities are necessary whenever there is any doubt.

6.0 ANTI POLLUTION STRATEGIES FOR ARCHIVES

The preceeding sections have indicated the diversity of pollutants and their various external and internal origins. Constant vigilance and curiosity are necessary before any preventative actions can be planned. Although each archive will be different especially in the technical, financial and human resources, some general principles can be followed as far as the local situation permits.

A long term programme which takes account of the whole local environmental scenario should be prepared and revised regularly. In devising this plan it is useful to follow these types of possible action.

1 Elimination of the sources of pollution

2 Prevention of pollution from entering the building

3 Removal or deactivation within the building

4 Protection of records by small enclosures

In most cases any improvements will be very gradual, it must always be regarded as a long term ideal that can begin to be realised immediately.

6.1 Elimination of the sources of pollution

Any reduction in the general level of external atmospheric pollution must involve great technical and administrative changes. These will always be costly, difficult and slow. Archivists will seldom have a dominant role in the formation of general pollution policies because so many other interests are involved, such as health, corrosion, effects on forestry and agriculture to name but a few. It is important to recognise that any improvements made for the benefit of other interests are to be welcomed by the archivist. Therefore a knowledge of other aspects of general pollution control will be helpful in determining the long term technical policy for the archive itself, otherwise there might be a wasteful duplication of resources.

Antipollution and clean air regulations operate in various ways but some of these might be;

- using fuels with reduced sulphur content, principally coals and oil.

- washing flue gases, removing particulates and discharging the remainder at a great height.

- eliminating the lead content of petrol.

- substituting alcohols or liquified gases for motor fuels.

- forbidding the burning of rubbish and wood.

It is likely that pollution generation close to an archive building might be more easily avoided but only after a careful survey of local resources, especially industrial plants. With this knowledge it might be possible to adjust the direction, siting and control of ventilation intakes into the archive to avoid or reduce the amount of pollutants admitted. Both the wind and the pattern of pollution generation vary very much throughout the day and it would not be very difficult to reduce their effects by simple measures. It might be better to shut off the ventilation for short periods of time when the pollution was at its worst. There is room for some ingenious planning on these lines.

Inside the archive corrective action can begin very quickly, but it would need to be maintained almost indefinitely. A review of all the activities which use materials would reveal sources of pollutants. All building maintenance and repair plans should be scrutinised. Cleaning processes and also the means of waste disposal should be investigated. Such enquiries will usually indicate what is causing local pollution and alternative methods or materials may be proposed.

The collections themselves should be inspected to identify those materials which are known to emit damaging chemical vapours. In particular cellulose nitrate, in the form of films, negatives or collodion prints should be segregated as a matter of urgency. They are also highly flammable. The survey would also reveal the extent of other undesirable materials in and among the records. Such materials are noted in other parts of this study.

6.2 Preventing the entry of pollutants

It is necessary and useful for several people to have a full understanding of the ventilation system and its controls. Ideally all pollutants should be removed, but this is never possible, if only because collections have to be used and maintained by people who wish to work as normally as possible; an archive cannot be a sterile storehouse. The identification of the main pollutants and the location of the most sensitive archive records are important steps. In general it will not be possible to make a continuous chemical analysis of such small amounts of atmospheric pollutants because of the great costs involved and also because the concentrations vary so greatly. A close liasion with any other organisation which is already collecting pollution data in the neighbourhood would be a very great help.

Removal of pollutants in the ventilation system must have a high priority, whether or not air conditioning is available or being planned. The capital costs of air cleaning will be much less than full airconditioning. Moreover when plant failures occur they will not be so serious if only cleaning is carried out. There are many instances of damaging situations arising from airconditioning plants getting out of control. Even so the costs in energy of recirculating air in a building are not insignificant and will be greater when filters to remove the finer dusts are installed.

Washing air with water which is preferably alkaline is an

effective means of removing acidic and also salts and some particulates. But washing inevitably increases the relative humidity and therefore is not desirable unless the climate is naturally very dry or the plant has a dehumidification stage built in. Such extras increase the costs and complexity of any plant. It may be wiser not to wash out the pollutants unless the air can be dried conveniently and cheaply. Acidic pollutants can be removed in other ways.

The extent to which dusts can actually be removed requires careful consideration, especially where dusts are created by activities within an archive. Dusts are raised by all sorts of movements, and often in the course of cleaning operations. The recognition that ultrafine dust particles, often of acid sulphates, permeate most districts and are too fine to be filtered out or ever settle completely on surfaces, makes a completely dust-free archive an impossibility. Coarse filterable dust particles should be filtered out as much as possible, though the reason for this is not entirely chemical. They soil the records, and also implant abrasive hygroscopic material. The organic components provide a source of food for micro-organisms.

Activated charcoal carbon absorbing filters are very effective in removing pollutant gases and vapours. Nitrogen oxides seem to be more difficult to remove than sulphur dioxide. Monitoring of archives in the Netherlands has shown much higher levels of acid gas pollution in winter. Studies on actual archives will always be rare because extremely sensitive and very expensive analytical apparatus is needed to give accurate figures. The rapid variations in pollution concentration makes the interpretation of small amounts of data very difficult.

Separation of fine dusts is possible with electrostatic precipitators but as these are liable to generate ozone and nitrogen oxides from the electrical discharges, they are not recommended, because ozone and nitrogen oxides degrade most record materials.

Air cleaning plants have practical limitations. An important consideration is the proportion of new air admitted, especially in polluted urban areas. Cleaned air should be recirculated as much as possible, but the recirculated air should pass through a cleaning plant because it will have become contaminated from many sources and activities within the archive building.

In many situations it may be better to consider the installation of smaller, perhaps mobile filtration and absorption units, particularly near more sensitive records. These could prove very convenient, for, if being essentially mobile, they could be easily supplemented if need be, or taken away for maintainance or filter changing. Such equipment would possibly be much less expensive than central large scale installations. Moreover, they would direct the technical and financial resources to the protection of the most sensitive part of an archive.

In all such plants the efficiency of the filters and absorbants must be maintained and a generous programme for replacement must be operated. After building repair, decoration or maintainance, more frequent changing would be justifiable. Whilst there are some very exacting standards published for archives and libraries it is almost always difficult to determine

in practice how far an individual archive deviates from these recommended levels of pollution. Accurate continuous monitoring will seldom be possible, but it is possible to arrange more simple systems. If samples of sensitive materials are exposed on a routine basis in various parts of the building, they could be withdrawn for analysis and testing at intervals. Thus some record of average pollution levels could be made and any pollution counter measures checked against it during an annual pollution audit. Dusts, acids, oxidising agents and hydrogen sulphide could with some assistance from scientists and technical people, be monitored using existing techniques.

6.3 Deactivation of pollutants within an archive

Deactivation is the ultimate defence against attack and the materials and contents of buildings play a big part in the absorption of pollutants. It is known that buildings of themselves reduced the sulphur dioxide concentration by about one half. It is absorbed by the stone, cement, concrete, woodwork and furnishings. Ozone is similarly reduced, being unstable it gradually changes back to oxygen. It is proper therefore to consider if this capacity for absorption can be increased as it is clearly much less costly than a central plant. At the same time it will become evident if any unsuitable materials are deployed within the building and contributing to the pollution by their emissions. Generally the prime target will be acid pollution, hence alkaline building materials such as cement and lime plasters would be desirable as absorbants, the difficulty is that they would create dusts unless sealed in a way which did not prevent their acid absorption. These ultra fine alkaline dusts are known to be harmful after they settle on record materials and humidity detectors.

Cellulose itself retains sulphuric acid and therefore all sorts of renewable hangings of wall paper and textiles would prove helpful. They would have to be placed in a way that would not increase the fire risks, and possibly they should be fire proofed as well. Impregnation with sodium borate (borax) will assist in both ways.

Attempts to prevent the spreading of fine dusts by sealing these surfaces may create more pollution when paints and varnishes dry. Full technical consideration of the coating and sealing materials is always desirable.

There is much scope for ingenuity in this field, and for many more experiments.

6.4 Protection of records by small enclosures

Cupboards, display cases, filing cabinets and boxes all offer some degree of protection against pollutants of all kinds. In reviewing any archive each enclosure should be carefully considered, not only as a pollution barrier but also as a means of reducing handling and transportation damage, and as a general security precaution as well as a final obstacle to hazards associated with fire and flood.

The difficult questions concern the need for ventilation. If

pollutants are being generated within an enclosure then they must be either vented away to the local atmosphere or absorbed safely within the enclosure. When there is doubt these precautions should be taken.

Exhibition showcases are often required, as in the case of parchment manuscripts exhibitions, to maintain a constant humidity. It is often convenient to achieve this with appropriate quantities of hygroscopic buffering materials (silica gel or nikka pellets), but such cases need to be as airtight as possible and hence could entrap pollutants and damage objects.

Such cases may be made of unsuitable materials such as plywood or chip board, but if lined with aluminium foil which is totally impermeable to all gases and vapours, a safer system is easily achieved. Aesthetic considerations demand a further layer of some safe material such as cotton cloth.

Wooden storage units should not be unventilated, for it is usually very difficult to seal the surfaces with impermeable foils. Ideally they should be replaced with metal cabinets with a 'safe' heat cured paint coating.

With boxes the airtightness of the seal ought to be determined by the nature of the box and the contents, based on the consideration that internally generated pollutants might be trapped. A balance between external and internal pollution sources has to be judged, usually with very little information.

All boxes and files will have, some access to the outside air, either by leakage through gaps or by permeation through the wood or paper boards. Often 'acid free' or buffered box material cannot be afforded, though in such circumstances it should be practicable to wrap the contents in chalk laden acid free papers, or perhaps to line the boxes with such papers using a safe adhesive, perhaps a starch paste.

As an extreme precaution, activated charcoal could be included, perhaps in a cotton sachet. But it is probable that only very special and sensitive objects could be protected in this way.

Photographic materials require the most stringent conditions and might properly qualify for such special considerations. There is much scope for long term research and development to determine what improvements might be made by such simple measures. The large number of boxes and enclosures in archives makes it necessary to select priorities carefully.

7.0 FORECASTING POLLUTION

The need for a long term plan has been indicated in this study, and whilst within the timescale of possible local improvements, archivists might do well to look far ahead and consider what the future might be. If the requirements of health and ecology make steady progress in reducing pollution then it will gradually bring about a life style which is inherently cleaner, and obviously better for the archives.

In the meantime fuel combustion is the main source. If and when petroleum consumption diminishes, we might well expect to have more coal being burnt, probably even poorer grades with more sulphur to pollute the air. Woodburning is not pollution free, but it can in principle depend upon a perpetual supply of timber. Further developments of nuclear energy are not likely to add to chemical pollution of the air.

More serious and uncertain are the changes in climate which have ample precedents in the fossil record but which might arise fairly quickly. If the average temperatures should rise, perhaps as a result of changes in the absorbtion of solar energy in the upper atmosphere then the control of conditions in archives would be exceedingly difficult and expensive. Buildings which are not very well insulated would then require very expensive air conditioning plant. Should the climatic predictions be quite incorrect, it could be reassuring to note that the degradation processes all diminish at lower temperatures. The design and planning of buildings for long term use is a difficult but worthwhile task which archivists need to cultivate along with many other professionals.

8.0 POLLUTION AUDITING

In this study the various sources and effects of pollution have been discussed. Whilst much of our knowledge is essentially indirect and inferential, improvements to collections and knowledge will result from a regular audit. Some suggested questions and issues are proposed here, essentially a rough guide to the enquiries. The formal questions will be extended and modified to suit each particular circumstance.

8.1 External pollution

Are pollution records of gases and particulates kept by any other organisation and are they useful in your own premises ?

Have they shown any significant changes related to climatic conditions ?

Are there any changes in industrial pollution or the burning of fuels in large installations nearby ?

Is it possible to restrict the air input into the archive at times of maximum aerial pollution ?

8.2 Activities creating pollution

What fumigants and biocides have been used on the premises ?

Where are they now ?

Are they potentially harmful to records ?

Do their residues remain within the collections ?

Have any new products or processes been used for cleaning the building and its furnishings ?

What has been done to avoid raising dust during cleaning operations ?

What building and repair work is planned and what precautions to minimise dust and pollutants being dispersed during the work ?

What activities in photography, copying and conservation create pollutants ? How can they be reduced ?

8.3 Ventilation system

Is the air intake situated and operated to minimise the admission of pollutants ?

How is the system cleaned and with what materials ?

Are any of these materials harmful to the records ?

Can they be avoided, eliminated or diverted from the records until the danger point is past ?

When are the filters and absorbers changed ? How is their efficiency measured or estimated ?

8.4 Internally generated pollution

Have all the cellulose nitrate materials and their wrappings been removed from the main collections and kept safely under supervision ?

Are any films or laminations made with cellulose acetate showing any signs or smells of degradation ?

What progress has been made in ensuring that the photographic materials are packed in the proper manner ?

What has been done to identify and replace or obscure by masking materials that are expected to emit harmful vapours and gases, and particulate dusts ?

What steps are being taken to avoid the creation of dusts by eliminating sources and any activity that might cause settled dust to become airborne again ?

In sound, tape and microfilm areas what precautions are taken or required to reduce the effects of dust ?

What steps have been taken to protect important complex historic objects from pollution and other harmful environmental influences, especially if put on display ?

9.0 CONCLUSIONS

Improvements in the care and management of archives and records will always be a gradual and probably a very slow process. It is therefore wise to formulate a long term plan which must include the reduction of pollution. Other factors such as temperature and relative humidity will also need attention and adjustment.

Apart from the ubiquitous oxygen and water, which bring about the ultimate decay of organic matter, the pollutants in archives are recognisable and to a degree, manageable almost independently of other considerations. Pollutants which are acidic, oxidising or dusty are the main risks. They can be reduced through general ecological improvements in the environment, or their access to the archive may be restricted by the judicious control of the ventilating systems which should wherever possible be equipped with the best available filters and absorbers. Such purification devices can be confined to the storage areas and re-circulate all the the air. The removal of pollutants by filtering and absorbtion can also be managed with portable re-circulating apparatus. Air purification which involves humidification or ozone generation is to be avoided. As the furnishings and fabric of the building act as absorbers their role can be further developed by simple measures.

Every effort should be made to reduce the pollution generated internally from fumigation, copying, conservation and cleaning. Some of these operations may be effectively separated from the ventilation of the record storage area, but in these areas some aggressive chemicals will be emitted slowly over long periods of time from some apparently innocous materials. If these are confined closely their effects may be rapid. The peroxides which attack photographic materials and the organic acids that corrode lead are the major risks. But with the increasing use of plastics and new formats the pollutions emissions from records and the materials around them should be scrutinised regularly. Particular care must be taken with well sealed enclosures because they prevent micropollutants from being ventilated away. Some extra provision can be made for them to be safely absorbed within, but is is practicable only for objects at the greatest risk. In the display of archival matter the same protective principles apply, but even more strictly because, in a showcase there will be new and fresh materials emitting pollutants and yet not much buffering material around to absorb them, except the exhibits themselves.

Pollution reduction requires a long term commitment and vigilance. It needs the occasional services and advice of analysts, maintenance engineers and materials scientists to monitor and warn. It is an important factor to consider when making any design changes in an archive.

10.0 BIBLIOGRAPHY

Introduction

In this wide ranging topic a full bibliography is potentially so long that it would be of little practical use. Articles, books and journals have been selected to exemplify the sources of information and ideas used in this study. Many of them are of varying significance and are also appropriate to several parts of the test. Brief comments and outlines are given for the references to assist in any further exploration by readers. The number of references given in each cited reference is also quoted for such further researches, aimed at more detailed points.

In such a wide study the use of 'On line' computer information systems was attempted, but for some of the specialised enquiries only a few references were found in these pilot studies. It is therefore expected that the prediction of effects of pollutants on a variety of complex materials will depend very much on general practical and chemical knowledge, rather than in searching for particular precise studies. These will become available only when preservation research becomes prolific.

Air pollution and aspects of polymer degradation
Cook I
ICCM Bulletin 1975 2 (4) 4-20
A useful review article. Natural sources of sulphur dioxide from oxidation of hydrogen sulphide from rotting are significant. Rosin sizing of papers increases the absorption of sulphur dioxide. Parchment, vellum and vegetable tanned leathers are less likely to be damaged by sulphur dioxide. Ozone attack of rubbers and cellulose derivatives (methyl cellulose) is noted, it also sensitises the oxidation of poly(ethylene). Nitrogen oxides are particulary noted for their attack on polyamides (nylons) (15 refs)

Air pollution from the oxides of nitrogen in the United Kingdom
Derwent R G, Stewart H N M
Atmospheric Environment 1973 7 385-401
Sources and detailed distributions are presented and related to the USA and world figures. Electricity generation, industry and transport are the main sources. Rain eliminates and limestones absorb it. (Traffic is likely to be the main source near urban areas.) (39 refs)

A simple test to identify gases which destroy silver images
Weyde E
Photographic Science and Engineering 1972 16 283-286
Brown spots on silver images were associated with oxidising gases and formaldehyde. Traffic and packaging materials, especially newly made plastics are suspected. Extreme care is necessary in selecting photographic packaging materials. A sensitivity test is described. (3 refs)

A rapid test for the detection of substances which will tarnish silver
Daniels V D, Ward S
Studies in Conservation 1982 27 58-62
Substances containing sulphur might emit hydrogen sulphide and so form black silver sulphide on silver. Quick identification is possible by their catalytic effect on the breakdown into bubbles as sodium azide solution. Photographic storage materials can be quickly tested but safety precautions are necessary.
(5 refs)

Trouble in store
Padfield T, Erhardt D, Hopwood D
IIC Science and technology in the service in conservation
Washington 1982 24-27
A wide ranging but detailed account of the effects of pollutant emissions on historic objects. Extensive examples are given. Pollutants from woods, papers, boards, varnishes, cleaning materials, biocides, paints, adhesives, textiles, and plastics are discussed. Cellulose acetate may after a critical time decompose very rapidly, but samples from different batches varied greatly.

Residential wood burning and air pollution
Quraishi T A
Int. J. Environmental Studies 1985 24 19-33
A useful summary of the complex combustion processes and products, eg very fine particulates, oxides of nitrogen, some sulphur dioxide, many volatile organics including aldehydes. Wood burning and rubbish incineration creates many substances harmful to records. (47 refs)

Formaldehyde release rate coefficients from selected consumer products
Pickerell J A, Mokler B V, Griffis L C, Hobbs C H, Bathija A
Envron. Sci. Technol. 1983 17 753-757
Many consumer products release formaldehyde (methanal) into the air. Examples include pressed wood products (chip board), textile fabrics, carpets, new clothes, fibreglass insulation.

The ozone fading of traditional natural organic colorants on paper
Whitmore P M, Cass G R, Druzik J R
Journal of the American Institute of Conservation 1987 26 45-48
Extensive studies of pigments exposed to similar urban Californian atmospheres for 12 weeks showed extensive fading. Indigo, madder lakes, Dragon's Blood and circumin were strongly affected. The exposure approximated to eight years in a showcase in an air conditioned building. (20 refs)

The damaging influence of disinfecting agents on sensitive ancient materials
Jedrzejewska H
IIC Climatology Conference London 1967 95-100
A useful review of the chemical effects and degradation caused by five biocides, p dichlorbezene, DDT, pentachlorophenol chloronapthalene, p dichlormeta cresol. Pigments and papers may be affected. Sealed containers may trap harmful vapours. Much more testing is needed. (24 refs)

Air pollution and the archivist
Daniels V D
J. Soc. Archivists 1979 6 154-156
A general review of the effects of hydrogen sulphide, sulphur dioxide, water, organic compounds, especially acids, on metals, pigmnets, skin products and paper. The need to test materials is stressed. Wrapping layers of pure cellulose paper absorbs much pollution and protects the objects. (4 refs)

An unsuspected danger in display
Oddy W A
Museums Journal 1973 73 27-28
Lead and silver may be attacked by vapours from adhesives woods and textiles when enclosed, as in show cases or boxes. A test method is described to predict pollution damage, to assist designers in the British Museum. (3 refs)

The chemistry of atmospheric pollution
Haagen-Smit A J
IIC Climatology Conference London 1967 89-94
A useful general review noting the unusual chemical reactions at very low concentrations. Filtrations and scrubbing (water washing) do not remove all the pollutants, notably ozone and oxide of nitrogen. Dust filters followed by activated charcoal fillers are recommended. The fading of some dyed fabrics and the effects on stone, metals and rubbers are discussed. (9 refs)

Studies on the nature of urban air pollution
Waller R E
IIC Climatology Conference London 1967 65-68
In a general review, the large proportion of very fine particles is noted. Smoke levels inside naturally ventilated buildings are similar to those outside. Sulphur dioxide is absorbed onto walls and textiles. Humans cause emissions of ammonia leading to particulate ammonium suphate crystal deposition. The humidifiers in an art gallery air conditioning system removed some sulphur dioxide. (2 refs)

Control of atmospheric pollutants and maintenance of stable climatic conditions within museum buildings
Carver T H
IIC Climatology Conference London 1967 23-29
The merits of various filtration devices are considered. Absorbtion figures for various gases and activated charcoal are given. (8 refs)

Wood coatings for display and storage
Miles C
Studies in Conservation 1986 31 114-124
Emissions from various woods and coatings were studied. Many examples of unsuitable materials were listed. Corrosion is the major risk, though at less than 50% RH it is much reduced. (38 refs)

Indoor air pollution-effects on cultural and historic materials
Baer N S, Banks P N
Int. J. Museum Managament & Curatorship 1985 4 9-20
An important comprehensive review covering most materials and pollutants of external and internal origin. Pollution levels and means of reducing them are discussed. Various official standards are outlined and considered.

Preservation of photographs
Eastman Kodak Company 1979 ISBN 0 87985 212 7
A full comprehensive and practical review of photographic materials, processes, storage conditions and preservation. Micro and macro environments are considered in detail. Coloured films and prints are best kept at a low temperature and a low humidity.

Air pollution-a review for conservation chemists
Thomson G
Studies in Conservation 1954 147-166
A thorough review of most forms of atmospheric pollution with a useful discussion of the efficiency of filters. (49 refs)

The museum environment
Thomson G
1986 2nd ed Butterworth & Co ISBN 0 408 01536 5
This edition updates experience with environmental control. This comprehensive work includes a useful chapter on air pollution, its sources, effects and removal. Details of filtration and absorbtion are discussed.

Indoor climate
McIntyre D A
1980 Applied Science Publishers (London) ISBN 0 85334 868 5
This comprehensive work contains a chapter on air quality and discusses internal and external pollution.

Preservation of historical records
National Research Council
1986 National Academic Press USA ISBN 0 309 03681X
This important book pays particular attention to pollution and environmental matters, including discussion of standards for clean air and chapters on photographic materials and magnetic recording media.

Sorption of sulphur dioxide by indoor surfaces and wallpapers
Spedding D J, Rowlands R P
J. Applied Chemistry 1970 20 143-146
Sulphur dioxide is absorbed and retained by paper. Coatings reduce the capacity greatly. Deposits of perspiration (sweat) also absorb sulphur dioxide. (9 refs)

Alkaline material liberated into atmosphere from new concrete
Toishi K, Kenjo T
J. Paint Technology 1967 39 152-155
Odours from concrete are considered to be extremely fine particles of alkaline oxides and silica. They penetrate cellophane films and affect drying oils, silk fibres, indigo dyed silk and glue bound lead oxide pigments on paper. (Many archive materials will be affected by such fine dusts).

Chain scission by small concentrations (1-5ppm) of sulphur dioxide and nitrogen dioxide respectively in presence of air and near ultraviolet light.
Jellinek H H G
J. Air Pollution Control Association 1970 20 672-674
Vinyl polymers are not much affected by sulphur dioxide in these conditions but nylon (polyamide) and elastomers (rubbers) are affected. Poly(ethylene) and poly(propylene) become crosslinked ie. harder. (14 refs)

Air pollution by particles
Shaw R W
Scientific American August 1987 84-91
An awareness article about the origin of ultra fine particulates and their acidic nature. Their sulphates and chlorides from the seas travel long distances and are more acidic than the coarser particles. Acidic fine particles are traced to coal burning. (Ultra fine particles are very difficult to remove from air, and are found at very remote rural sites).

Air conditioning for museums
Harvey J
Museum Journal 1973 73 11-16
Temperature, humidity and pollution control are discussed with practical details. (12 refs)

Particles in the atmosphere - natural and man made
Davies C N
Atmospheric Environment 1974 8 1069-1079
A usesful survey indicating the widespread pollution by extremely fine particles, much of which is produced from trees, forest fires, vegetation, algae and marine plankton and by polymerisation by light of terpene compounds from pine trees. Industrial and urban sources are also noted, but are largely localised. Of the coarser particles many of these are also of natural origin ie. from ash, smoke, ground dust, spores, fibres skin scales, and salts from the seas.
(Whilst recognising the great importance of industrial pollution, there will still be a general problem even if man made pollution were ever stopped.) (29 refs)

Selecting safe materials for use in the display and storage of antiquities
Blackshaw S M, Daniels V D
ICOM Conservation Committee Conference Zagreb 1978 78/23/2/1-9
Discusses testing of materials for storage and the absorption of ethanoic (acetic) acid on glass and silica gel. (18 refs)

Choosing materials for prolonged proximity to museum objects
Hopwood W R
A I C Preprints Toronto 1979 44-49
Test procedures to detect volatile acidic materials are described. Useful results are obtained in 4 days. (4 refs)

Microenvironments
Baer N S, Banks P N
Int. J. of Museum Management & Curatorship 1987 6 301-305
This discussion article considers the characteristics of many types of enclosure and the materials used. The extent of free air space and the desirability of venting boxes is considered. (10 refs)

Some aspects of the conservation of works of art in buildings of new concrete
Toishi K, Kenjo T
Studies in Conservation 1975 20 118-122
Extremely fine alkaline dusts arise from concrete and affect drying oils, silk, painted paper, and the calibration of hair hygrometers. Buildings as old as ten years may continue to be polluted in this way. (4 refs)

Concentration, decay rates and removal of ozone and their relation to establishing clean indoor air
Subersky R H, Sinema D A, Shair F H
Environmental Science & Technology 1973 7 347-353
Studies in offices, homes and test chambers show that ozone decays faster in the presence of cotton or wool. In air conditioning systems activated charcoal is very efficient but glass fibre filters were ineffective. Ventilation may add considerably to the internal ozone levels. (27 refs)

Carbonyl sulphide-potential agent of atmospheric sulphur corrosion
Graedel T E, Kammlott G W, Franey J P
Science 1981 212 663-664
Carbonyl sulphide occurs in similar concentrations over wide areas, unlike other sulphur pollutants. Natural sources are predominant, but it arises from microbial activity, volcanoes, burning vegetation and industrial processes. (31 refs)

Measurement of the effect of air pollution on paper documents
Langwell W H
J. Soc. Archivists 1978 372-373
Describes a simple test strip which changes colour as sulphur dioxide pollution is absorbed. It is proposed as a simple monitoring device for archives.

Indoor/outdoor ozone concentrations at a contemporary art gallery
Davies T D, Ramer B, Kaspyrok G, Delany A C
J. Air Pollution Control Association 1984 34 135-137
Ozone attacks cellulose and proteins. It decays to oxygen at various surfaces in the building, cellulose is particularly effective. Air conditioning may not reduce the ozone concentration, as found at the Sainsbury Centre at Norwich (UK).

Disclouration of black and white photographic prints
Feldam L H
J. Applied Photographic Engineering 1981 7 1-9
Environmental effects noted include the effects of applied alkyd paints and the general use of cosmetics. (Alkyd drying and chemistry is similar to that of drying oils.) (22 refs)

Historical survey of research at the National Bureau of Standards in materials for archival records
Wilson W K, Parks E J
Restaurator 1983 5 191-241
In a very comprehensive survey much original work is summarised, notably on acidity, the stability of cellulose acetate, microfilm and magnetic tape. (177 refs)

Decomposition rates of ozone in living areas
Mueller F X, Loeb L, Mapes W H
Env. Science & Technology 1973 7 342-346
Ozone decays naturally, but more slowly at lower humidities and temperatures. Furnishings assist greatly in eliminating ozone. Half lives of 1 to 30 minutes are indicated. (It seems probable that ozone would not affect materials in boxes in an archive.)

The testing of materials for use in storage and display
Blackshaw S M, Daniels V D
The Conservator (UKIC) 1979 3 16-19
Emissions of organic acids and hydrogen sulphide from woods, wool protein, and sulphur dyes are discussed. Polymers with acetate or chlorides may also emit corrosive substances. The corrosion of samples of copper, silver and lead forms the basis of a test for storage materials by exposure in a hot humid atmosphere. Acidity in organic materials such as paper and boards is tested by measuring the pH of aqueous extract. Regular testing continues at the British Museum. (10 refs)

Volatile amines used as corrosion inhibitors in museum humidification systems
Volent P, Baer N S
Int. J. Curatorship & Management 1985 4 359-364
Humidification by atomising and spraying of tap water causes mineral dust to be scattered around. If instead treated boiler water is used, the treatment chemicals may also be dispersed. Possible examples are - sodium hexametaphosphate, hydrazine, morpholine and diaminoethanol. Significant health problems occur and oily films have been found on many museum objects.

The oxidation of cellulose by ozone in small concentrations
Bogaty H, Campbell K S, Appell W D
Textile Research Journal 1952 81-83
Ozone at typically atmospheric concentrations damages wet cotton, in 50 days a 20% loss of strength was found. Dry cotton was hardly affected. (Dry conditions often reduce chemical degradation.) (9 refs)

Archive buildings : international comparisons
Thomas D L
J. Soc. Archivists 1988 9 38-44
A discussion paper pointing out the problems of old and new buildings and the need for adequate control over ventilation. (37 refs)

The problems of formaldehyde in museum collections
Hatchfield P B, Carpenter J M
Int. J. Museum Management & Curatorship 1986 5 183-188
Formaldehyde is emitted by many materials for long periods of time. Urea formaldehyde glues are the most probable. Its active reducing powers can alter images and harden proteins. After the oxidisation it becomes formic acid which attacks metals and objects containing calcium carbonate. Silica gel and activated carbon are not very effective absorbants. This is a most useful publication. (14 refs)

Certain deterioration factors for works of art and simple devices to monitor them
Kenjo T
Int. J. Museum Managment & Curatorship 1986 5 295-300
Attention is drawn to the effects of dust and volatile components as pollutants. Simple test strips are proposed, with linseed oil, a selection of pH indicators, a dyestuff and lead oxide. Such testing methods can be used by organisations without extensive analytical facilities.

International Standards

ISO 6051 - Storage of photographic prints
ISO 5466 - Storage of safety photographic film